Status of the Multiply-Charged Ion Research Facility at JPL

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(September 22, 1996)

ABSTRACT

In order to provide a better understanding of the energy balance and ion composition in solar, stellar, and planetary atmospheres, and in the interstellar medium, a new research facility for the study of interactions of multiply-charged ions has been developed at the Jet Propulsion Laboratory. A 1.2 tesla/14.0 GHz Caprice-type electron-cyclotron-resonance (Wit) ion source is used to produce highly-charged ions. The JPL facility can deliver icms into three experimental stations. Two are currently in operation for (a) measurement of absolute electron collisions] excitation cross sections, and (b) measurement of lifetimes and *f*-values of metastable levels. A third beam line is reserved for future experiments.

PACS number(s): 34.80.Kw, 35.80.+s

I. INTRODUCTION

The excitation of singly and multiply charged ions by electron impact plays an important role in understanding heating and radiation mechanisms in a variety of plasmas including the interstellar medium; solar, stellar and planetary atmospheres; x-ray lasers; and tokamak fusion reactors. An electron energy-loss technique for studying electron impact excitation was pioneered at the Jet l'repulsion Laboratory [1]. This technique was later extended to an energy-loss and merged-beams method to measure absolute excitation cross sections [2,3]. A major upgrade of the J] 'I, electron-ion collisions] research facility has recently been made by introducing a state-of-the-art, 1.2 tesla/14.0 GHz Caprice-type electron-cyclotron-resonance (ECR) ion source [4]. This source will significantly enhance the capability to perform excitation measurements in multiply-charged ions (M CIs). A Kingdon trap has been installed on a second beam line to measure lifetimes and *f*-values of metastable levels in MCIS [5].

II. THE ION-SOURCE AND HEAM LINE SETUP

The Caprice ECR ion source is a double-stage source in which a neutral gaseous or metallic component is introduced into the plasma chamber, and ionized via electron-impact ionization, The electrons are resonantly heated try 14 GHz microwave power supplied by a 2 kW high-power microwave amplifier and klystron. A superposition of radial and solenoidal magnetic fields in the ECR chamber traps the electrons and induces a high ion density by plasma neutrality. Successive ionizations of the ions produce the high charge states. The beam line is designed by using the SIMION charged particle optics software [6]. The ions produced in the source are extracted and focused at the entrance focus point of a double-focus 90° bending magnet, and then mass/charge selected and switched into one of the three experimental stations by using an electrostatic switching deflector. A schematic of the beam lines on the ECR system is shown in Fig. 1. Details of the experiments for measurements of collisional excitation cross sections and lifetimes of metastable levels can be found in previous publications [5,7],

1'0 meet the beam-energy requirement in our research, the ECR source is biased up to 10 kV, allowing beam energies of up to] $0q$ keV for ion charge state q. In our test operations, an oxygen beam with energy as low as $500q$ eV was obtained. A charge-state distribution was obtained by ramping the analyzing magnet current and measuring the argon ion currents with a Faraday cup installed at the exit focus of the magnet. An Ar^{11+} beam was obtained with only 100 watts of microwave power and a 2 mm diameter plasma electrode hole.

A wide variety of metallic-ion charge states are needed for astronomical studies. Besides beams of gaseous materials, metallic ions are produced by installing a special oven [8] to evaporate and ionize a small piece of desired pure metal. A Mg^{8+} beam of energy 80 keV was observed with a microwave power of 100 watts.

III. MEASUREMENT OF THE METASTABLE POPULATION

Ion beams produced by ion sources often contain a significant fraction of metastable states. The population depends on the ion quantum levels involved, ion transit time from source to scattering region, and the type and operating conditions of the source. In order to measure absolute electron-i~npact excitation cross sections in positive ions, knowledge of the metastable beam fraction is indispensable.

There are different ways to measure the metastable population in an ion beam [9-12]. If the ground state and metastable state have different charge-exchange cross sections, the attenuation method is the simplest one. One attenuates the ion beam in a gas-filled section of the beam line and measures the transmitted ion beam current as a function of gas pressure. A break in the slope of transmitted current versus pressure corresponds to different charge-exchange cross sections of metastable state and ground state. Extrapolation of the high-pressure slope to zero gas pressure will yield the metastable fraction of the beam.

A metastable search was performed for the ion beams produced by our ECR ion source, and a preliminary result for 10 keV Mg^+ ions in N_2 is presented in Fig. 2. A mass/charge selected Mg^+ beam was attenuated by N_2 gas, and the transmitted Mg^+ beam was collected by a Faraday cup. A clear discontinuity in slope is seen in the attenuation curve, and a 15% metastable fraction is indicated. Low-lying metastable levels in Mg^+ which can be significantly populated are 4s 2_s and $3d\,^2D$, as seen in Fig. 2.

In summary, we have reported the status of the multiply-charged ion research facility at JPL. Having the system operational, we are exploring its performance. The next phase of this effect will be to deliver beams of multiply-charged ions to the experimental stations.

ACKNOWLEDGMENTS

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was supported by the National Aeronautics and Space Administration. C. Liao and D. Hitz thank the National Academy of Sciences-National Research Council for support as Resident Research Associates.

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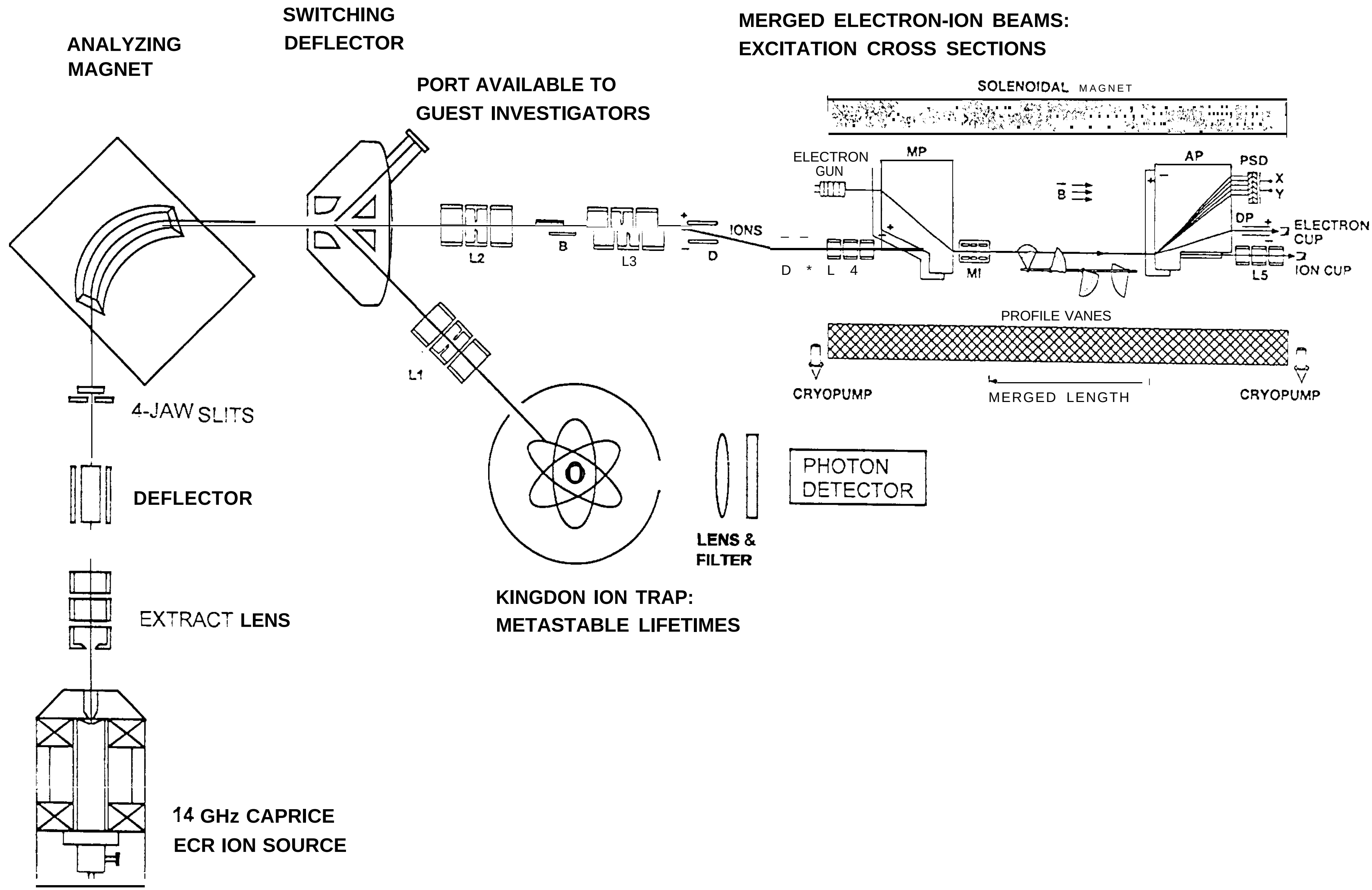
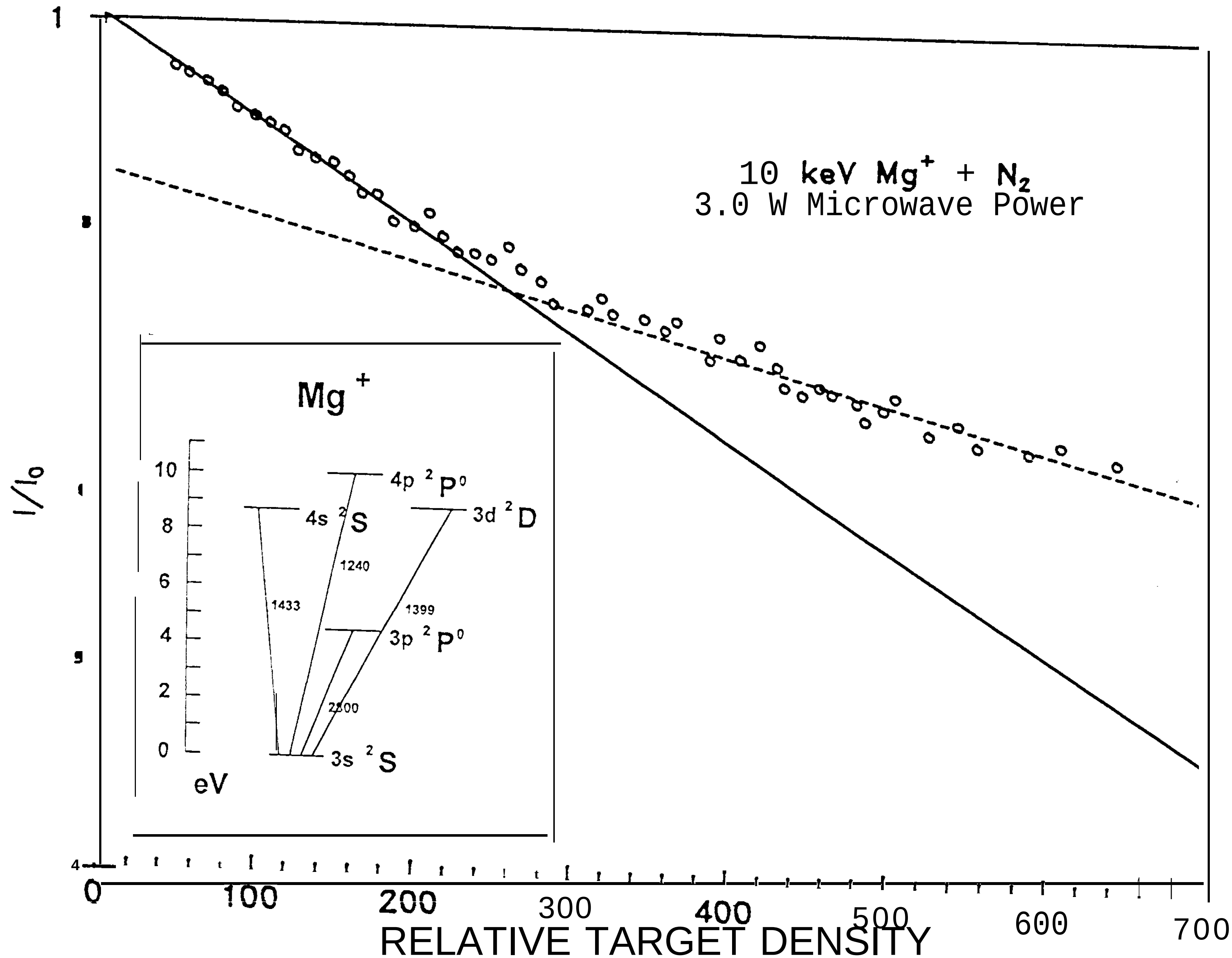
FIGURE CAPTIONS

Fig. 1 Schematic of the beam lines on the JPL Caprice multiply-charged ion source. (L1-L5) three-element focusing lenses, (B) differential pumping baffle, (D) deflector plates, (MP) merging trochoidal plates, (AP) electron analyzing trochoidal plates, (MI) electron mirror, (DP) trochoidal deflection plates to deflect parent electron beam out of the scattering plane, (PSD) position-sensitive detector.

Fig. 2 Attenuation curve of 10 keV Mg^+ ions in N_2, and partial energy-level diagram for Mg^+. A 15% metastable fraction is indicated.



SWITCHING
DEFLECTOR
ANALYZING
MAGNET
MERGED ELECTRON-ION BEAMS:
EXCITATION CROSS SECTIONS
PORT AVAILABLE TO
GUEST INVESTIGATORS
SOLENOIDAL MAGNET
ELECTRON
GUN
MP
AP
PSD
X
Y
B
DP
ELECTRON
CUP
ION CUP
L2
B
L3
D
IONS
D * L 4
MI
L5
PROFILE VANES
CRYOPUMP
MERGED LENGTH
CRYOPUMP
L1
4-JAW SLITS
DEFLECTOR
PHOTON
DETECTOR
LENS &
FILTER
KINGDON ION TRAP:
METASTABLE LIFETIMES
EXTRACT LENS
14 GHz CAPRICE
ECR ION SOURCE



10 keV $Mg^+ + N_2$
3.0 W Microwave Power
I/I_0
1
Mg +
10
8
6
4
2
0
eV
4p $^2P^0$
4s ^2S
3d ^2D
3p $^2P^0$
3s ^2S
1240
1433
1399
2800
0
100
200
300
400
500
600
700
RELATIVE TARGET DENSITY